Aircraft Optimization for Minimum Environmental Impact

NAG-1-2144 Final Report

Nicolas E. Antoine and Ilan M. Kroo

Stanford University

Abstract

The objective of this research is to investigate the trade-off between operating cost and environmental acceptability of commercial aircraft. This involves optimizing the aircraft design and mission to minimize operating cost while constraining exterior noise and emissions. Growth in air traffic and airport neighboring communities has resulted in increased pressure to severely penalize airlines that do not meet strict local noise and emissions requirements. As a result, environmental concerns have become potent driving forces in commercial aviation. Traditionally, aircraft have been first designed to meet performance and cost goals, and adjusted to satisfy the environmental requirements at given airports. The focus of the present study is to determine the feasibility of including noise and emissions constraints in the early design of the aircraft and mission. This paper introduces the design tool and results from a case study involving a 250-passenger airliner.

1 Introduction

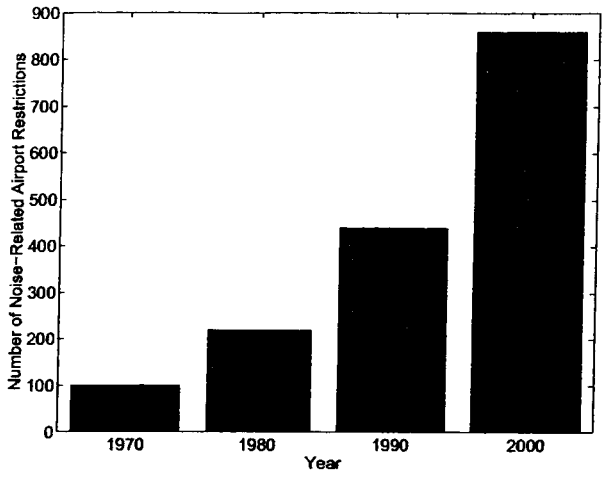

Figure 1: Airport-enforced Noise Restrictions.

In evaluating the potential for reduced noise and emissions of commercial aircraft, two environmental aspects are considered: noise pollution and emissions. In addition to the updated noise certification requirements to be introduced in 2006 by the ICAO and FAA, individual countries and airports are adopting their own stricter policies under pressure of local communities. A survey of the world's airports reveals a two-fold increase in the number noise-related restrictions in the past ten years [1]. These include curfews, fines, operating restrictions, and quotas (Figure 1). In particular, nighttime operations have been increasingly restricted. The second environmental influence considered here is the effect of aircraft on the atmosphere. Approximately 750 million tons of pollutants are released into the atmosphere by commercial aircraft every year [2]. Improvements in combustor technology have reduced the amount of NO_x and CO per aircraft, but the expected doubling of the fleet in the next twenty years [3] will result in an increasingly severe environmental (and political) problem. As a result, more countries are following Sweden in levying emission surcharges [4].

These fines and operating restrictions, especially in the case of noise, impact the design of new aircraft: Boeing is offering a low-noise version of its 747, and Airbus, at the request of airlines, has modified its A380 design to meet stringent London Heathrow nighttime requirements [5]. In parallel, engine manufacturers have made low-emissions combustors available as an option. These have been selected by airlines that operate from airports with operating restrictions or fines based on emissions levels.

Although modifications can be implemented on existing aircraft to meet current requirements, significant reductions in noise and emissions require more systematic consideration of such constraints. The approach taken here makes environmental performance an explicit design constraint rather than a post-design concern, providing the opportunity to study improvements to current aircraft configurations as well as unconventional designs that could provide dramatic reductions in noise and emissions, such as the Blended-Wing-Body [6]. By estimating the trade-off between operating cost and environmental acceptability, it is possible to define a range of aircraft based on the environmental performance required (Figure 2).

The foundation of the system is a series of routines used to compute many aspects of aircraft design and performance. Noise modeling is evaluated with NASA Langley's Aircraft Noise Prediction Program (ANOPP). Engine performance, dependent on bypass ratio, altitude, and Mach number, is estimated using NASA Glenn's Engine Performance code (NEPP). These routines, along with a nonlinear optimizer, are embedded in a multidisciplinary design framework [7].

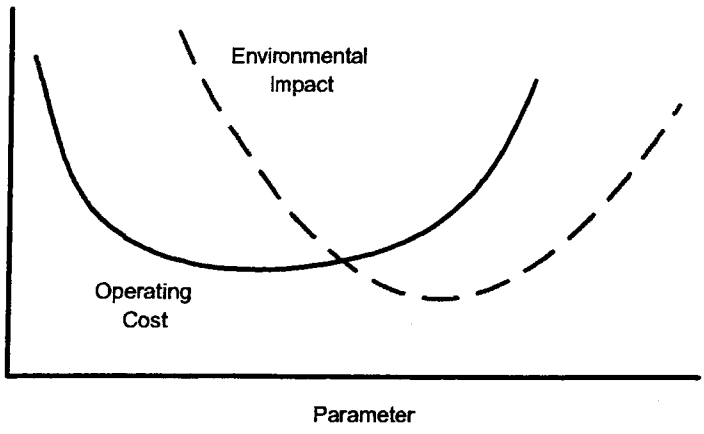

Figure 2: Design Challenge: the trade-off between cost and environmental impact.

2 Methodology

Engine performance, noise, and emissions modules are coupled to programs previously developed by the authors that compute performance and operating cost [8]. These approximate methods are particularly well-suited for optimization due to their rapid execution and robustness.

2.1 Engine Simulator

NEPP is a 1-D steady thermodynamics analysis program developed by NASA Glenn that allows design and off-design scenarios. At the design point, NEPP automatically ensures continuity of mass, speed, and energy by changing the scale factors on the performance maps for the compressor and turbine components. Off-design is handled through the use of component performance tables and minimization of work, flow, and energy errors. The engine is then balanced by altering free variables of available components. Variable controls can also be used to obtain a certain performance. For example, airflow or combustion temperature can be varied to reach a desired thrust level. Controls are also used to limit

and optimize engine parameters. Variables sent to NEPP from the optimizer include bypass ratio (BPR), sea-level static (SLS) thrust, and fan pressure ratio [9].

The baseline engine is designed to represent 2010 technology, including increased combustion temperatures and high turbomachinery efficiencies. Such a "rubberized" engine that can accommodate a large number of configurations has its limitations: bypass ratio is limited to values between 1 and 14.

2.2 Noise

Aircraft noise has been an area of extensive research since the early days of aviation. Its importance has grown with the industry and with the introduction of the turbojet. While high-bypass turbofans and lining materials have helped reduce noise by approximately 20 dB since the early 1960s [10], most airport communities would argue that there is room for further improvement.

Three measurement points are used by the ICAO and FAA for noise certification. Sideline, climb (also known as take-off), and approach noise (Figure 3) for commercial aircraft types must remain below a limit based on the airplane's maximum takeoff weight (and, for take-off, the number of engines). Jet noise typically dominates in sideline and climb. With increasing bypass ratios diminishing the engine's contribution to noise at low power, however, aerodynamic noise is an increasingly relevant component on approach.

NASA Langley's Aircraft Noise Prediction Program (ANOPP) is used to compute noise on takeoff and approach. ANOPP is a semi-empirical code that incorporates publicly available noise prediction schemes and is continuously updated by NASA Langley. The relevant engine data is passed from NEPP, and the aircraft geometry and take-off profile from the

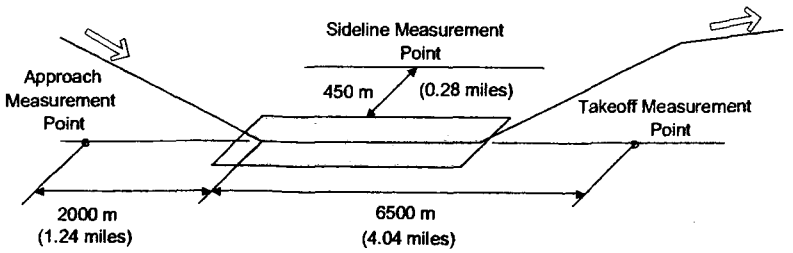

Figure 3: ICAO Noise Measurement Points.

other aircraft analysis routines. The modeled noise sources include fan noise, combustor noise, jet noise, and airframe noise.

The ANOPP fan noise module is based on the model developed by M. F. Heidman [11]. The components include inlet broadband noise, inlet rotor-stator interaction noise, discharge broadband noise and discharge rotor-stator interaction noise. The method employs empirical correlations to predict the sound spectra as a function of frequency and polar directivity angle. Combustion noise is computed based on the methods described in SAE ARP 876 [12]. Empirical data from turbofan engines is used to predict the sound spectra. Stone's method [13] is used to predict the coaxial circular jet noise. Because only high-bypass ratio subsonic engines are under consideration, shock turbulence interference is neglected, leaving jet mixing noise as the only component. The airframe noise sources include the wing, tail, landing gear, flaps, and leading edge slats. Broadband noise is computed using Fink's methodology [14], which employs empirical functions to produce sound spectra as a function of frequency, polar directivity angle and azimuth directivity angle.

Once the near-field sound spectra is computed for each noise source, the propagation module is run to determine the tone-corrected perceived noise level as measured at the ICAO certification points. Finally, the time-averaged Effective Perceived Noise Levels (EPNL) values are computed.

2.3 Engine Emissions

Both particulate and gaseous pollutants are produced through the combustion of jet kerosene, including: NO_x, CO, and unburned hydrocarbons (UHC). For a given generation of engines, maximum allowable emissions as set by the ICAO are a function of take-off pressure ratio and thrust.

In modern engines, NO_x emissions represent approximately 80% of regulated pollutants. CO and UHC levels have been significantly reduced with rising turbine inlet temperatures and improved combustor design. As shown in (1), emissions for certification are calculated based on simulated LTO (landing-take-off) cycle time, combustor emission index (EI), and thrust specific fuel consumption (SFC) at four different conditions: takeoff (100% throttle), climb (85%), approach (30%), and idle (7%).

$$\text{Emission (g/kN)} = \text{Emission Index (g/kg fuel)} \times \text{Engine SFC (kg fuel/hr kN)} \times \text{Time in Mode (hr)} \quad (1)$$

The two methods that allow a reduction in emissions include improving the combustor to yield a lower emission index (that is, reduce the amount of pollutant that is emitted per pound of fuel used) and choosing an engine cycle that yields a lower specific fuel consumption (reduce amount of fuel required). Increasing the combustor exit temperature and pressure improve SFC, but also raise NO_x emissions. Empirical correlations built into NEPP are used to predict NO_x emissions, by far the dominant pollutant produced during the LTO cycle.

This explicit modeling of engine performance also permits studies of other emissions, less commonly factored into the aircraft design process, allowing, for example, the design of optimal aircraft with constraints on CO_2 emissions or contrail formation [15].

2.4 Optimization

The examples shown here involved minimizing a measure of total operating cost, subject to performance and environmental constraints listed below.

CONSTRAINTS:	Noise
	Emissions
	Range
	Field Performance
	Climb Performance
	Stability and Trim
VARIABLES:	Bypass Ratio
	SLS Thrust
	Maximum Take-Off Weight
	Wing Geometry
	Cruise Performance

An important element of the current design approach is an optimization framework that allows integration of codes such as NEPP and ANOPP with other disciplinary analyses ranging from component weights to stability and control and mission performance. This was accomplished using a version of the Caffe framework [7] which facilitates the coupling of multidisciplinary analyses and optimization. In the present application, approximately twenty different analysis modules were combined with nonlinear optimization and a database management system to allow rapid reconfiguration of the design variables, objectives, and constraints.

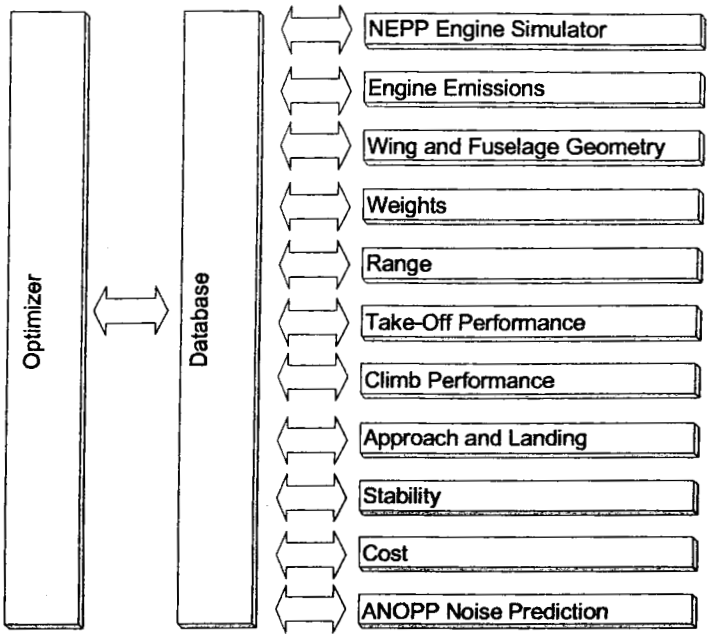

Figure 4: Basic Structure of Design Method

In addition to traditional performance constraints such as range and field performance, maximum allowable noise and emissions are included. This approach allows us to explicitly specify the extent of the increase in environmental acceptability: from slight improvements in noise to "silent" aircraft. Design variables include parameters from the aircraft configuration, propulsion, and entire flight profile.

The engine simulator (NEPP), is run first (Figure 4) as several engine characteristics are required by the performance analyses (e.g. range and takeoff calculations). The aircraft performance programs, which are run next, include subroutines that compute from range and take-off performance to structural details. Noise calculations (ANOPP) are run last. Several nonlinear programming methods are available to solve this type of optimization problem. Since initial tests involved only about 12 design variables, a robust but not very efficient constrained scheme based on a Nelder-Mead algorithm was employed.

3 Results

In order to validate NEPP-ANOPP interaction, initial parametric studies focused on the effects of engine bypass ratio on noise and operating cost.

3.1 The Effect of Bypass Ratio on Noise

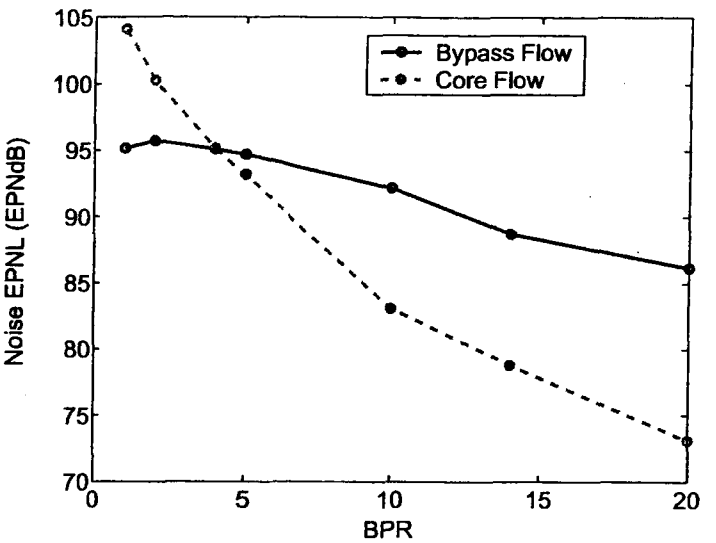

Figure 5: Noise vs. BPR

Increasing bypass ratio can have a dramatic effect on fuel efficiency, noise and emissions. By increasing the amount of airflow going around the combustion chamber relative to the amount of air going through it, mixing between the flows on exit is increased and exhaust velocities reduced. The result is a considerable decrease in jet noise. In this study, only engine noise is considered. Figure 5 illustrates the effects of increasing bypass ratio on the flyover effective perceived noise level (EPNL) emitted through the bypass (fan) and core flows of a 40,000 lb sea-level thrust engine.

As expected, both fan noise and core noise decrease as bypass ratio increases. Fan noise

does not decrease as rapidly as core noise: the larger fan contributes more to noise at higher bypass ratio, mostly due to the turbomachinery component. Increasing bypass ratio from 5 to 15 results in a flyover noise reduction of about 15 dB, a 30-fold reduction in sound energy. These results match those published by Kennepohl [16].

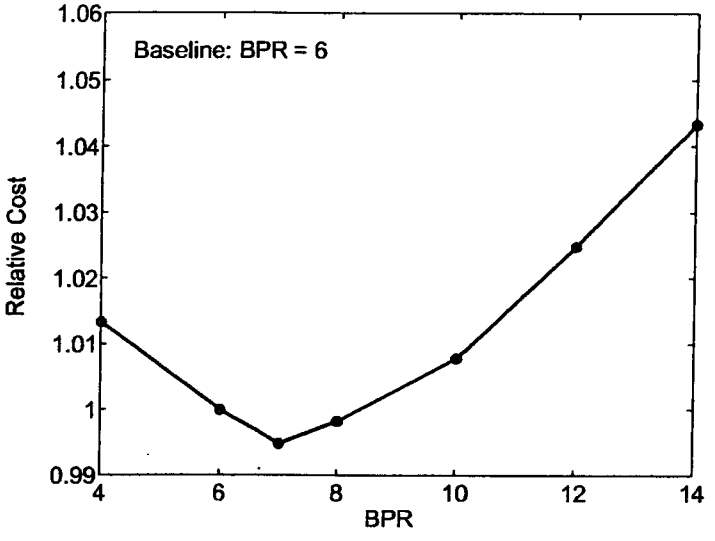

Figure 6: Cost vs. BPR

The advantage of increasing bypass ratio on operating cost is not as obvious. A higher bypass ratio usually demands a larger fan, increasing parasite drag. In addition, for a given thrust requirement at cruise conditions, a higher bypass ratio engine will require higher installed thrust at sea-level to offset the greater thrust and velocity lag. An engine with a BPR of 6, for example, would produce approximately 20% more thrust at 31,000 ft than an engine of equivalent sea-level thrust with a BPR of 10. Hence, increasing bypass ratio does not necessarily result in the most economical solution, as exemplified in Figure 6. Each data point represents an optimized design (twin-engine, 1500nm range, 100 passengers) with a fixed bypass ratio.

3.2 Case Study in Noise Reduction

Starting with a baseline, a 250-seat twin-engine, 4500nm range aircraft, the goal was to determine the cost impact of reducing cumulative noise (the sum of the noise at each measurement point) by 6 EPNdB. First, the aircraft was optimized without any noise constraints to obtain the design with the lowest possible operating cost; this is the reference aircraft. At this stage, the aircraft is already 20 EPNdB below ICAO Chapter 3 and 10 EPNdB below ICAO Chapter 4. The design was then optimized to meet the desired cumulative noise reduction. Results are shown in Table 1. The relative operating cost represents a measure of total operating costs based on the ATA method [17] for direct operating cost and more recent data from Schaufele [18]. Noise values at the measurement points for the optimized reference and low-noise designs are shown in Table 2.

The extent of the noise reduction for each noise source at the three measurement points is shown in Figure 7. Jet noise is the component subject to the greatest reduction after optimizing the aircraft.

The requirement for a cumulative reduction of 6 EPNdB pushed the bypass ratio to 9.47, in the process decreasing the core exhaust velocity at takeoff by 15%. As the fan gets larger (but required thrust stays approximately the same), the fan exhaust velocities also decrease by 15% and, as the fan pressure ratio decreases with increasing bypass ratio, the fan exhaust temperature decreases by 4%. However, fan turbomachinery noise remains the most difficult to minimize as bypass ratio is increased, which explains the low fan noise reduction. A larger fan does provide a greater area around the engine to install acoustic liners, however, and these might be used to offset some of the noise. While increasing bypass ratio has a considerable effect by lowering jet velocities, these are no longer dominant at high bypass

Design Variable	Reference	Low-Noise
MTOW (lbs)	319,904	331,790
Sref (ft^2)	3,018	3,232
Thrust/engine (lbs)	48,248	49,745
Initial Cruise Alt (ft)	30,613	30,080
Final Cruise Alt (ft)	40,063	42,528
Wing Location (% Fusel.)	41.80	37.70
Wing Aspect Ratio	7.66	7.99
Wing Sweep (deg)	26.76	32.25
Wing Thickness/Chord	0.116	0.139
Tail Area/Wing Area	0.25	0.22
Bypass Ratio	6.34	9.47
Relative Cost	1.00	1.01

Table 1: Optimization results

Location	Reference	Low-Noise	Change
Sideline	93.25	89.86	- 3.39
Climb	88.49	87.16	- 1.33
Approach	95.78	94.45	- 1.33
Cumulative	277.52	271.47	- 6.05

Table 2: Noise values (EPNdB)

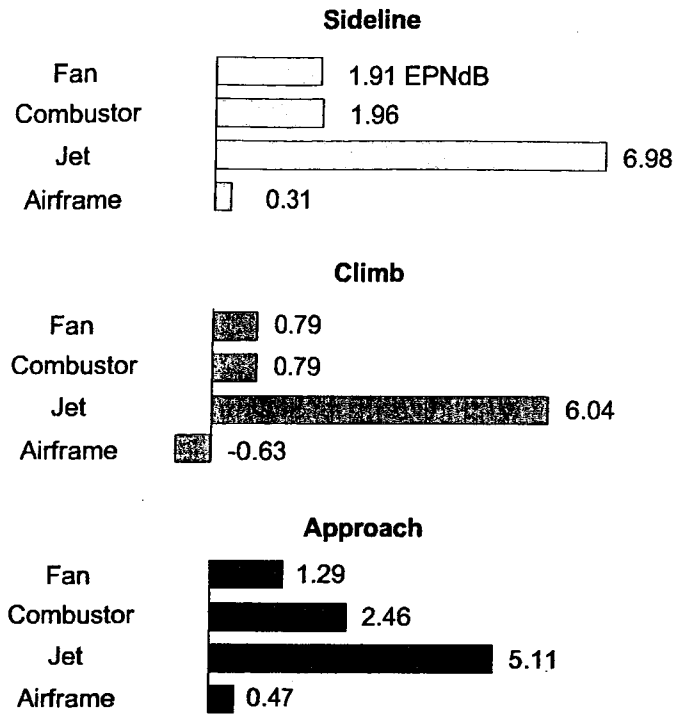

Figure 7: Noise reduction of low-noise design relative to reference.

ratios on approach. The large fan, and consequently, more important fan turbomachinery noise component, limit the potential of noise reduction on approach. Take-off and approach velocities are lower for the low-noise design, reducing airframe noise at these locations. On the other hand, as a result of the shallower climb angle of the low-noise aircraft, the distance to the climb measurement point is reduced, resulting in higher airframe noise. As expected, the higher bypass ratio engines of the optimized design feature greater sea-level thrust to compensate for the increased thrust lag at cruise conditions. The optimizer also attempts to lower the cruise altitude to reduce these lag effects, hence the higher wing sweep to reduce compressibility drag. The penalty for operating the low-noise design is a 1% rise in cost.

In the process, NO_x emissions were reduced from 19.1 g/kN to 14.5 g/kN, mostly due to the lower fuel flow of the higher-bypass ratio engines.

4 Future Work

The case study demonstrates how changing the entire aircraft to meet certain environmental constraints affects the operating cost. While small reductions in noise (2-3 dB cumulative) can be attained in practice by adding sound-proofing liners or by installing chevron nozzles, more important reductions will require redesigning the aircraft. The next step is to apply steadily more stringent environmental restrictions to determine the extent of noise and emissions reduction possible with conventional commercial aircraft configurations. The most challenging noise reduction location is approach. As a result, there has been considerable research on steeper descents — increasing the vertical distance between the measurement point and the aircraft [20, 19]. The design tool will be further enhanced to handle steeper descent options by adding approach angle (and related parameters) as a design variable.

Figure 8: The Blended-Wing-Body (Courtesy The Boeing Co.).

On the emissions side, adding combustor exit temperature as a design variable will provide more direct control over NO_x emissions and enable the trade-off between high temperatures for high efficiency and low temperatures for low nitrous oxide emissions.

NASA has set a goal of reducing aircraft noise by an additional 20 db in the next 25 years. However, increasing environmental acceptability by adapting conventional configurations will

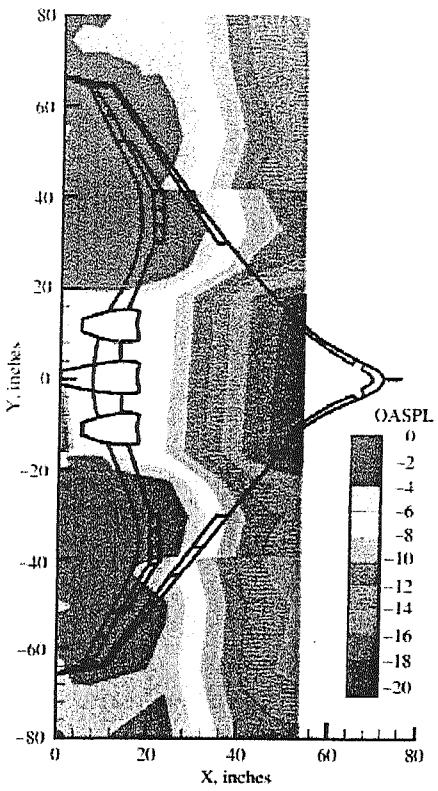

Figure 9: Noise reduction in the forward quadrant (Courtesy NASA Langley).

eventually become prohibitively expensive. Unorthodox concepts such as the Blended-Wing-Body therefore hold considerable promise. The Blended-Wing-Body burns substantially less fuel and requires less thrust than conventional aircraft at a similar technology level, resulting in an aircraft that inherently generates less noise and fewer emissions. Simply by virtue of this increased efficiency, BWB is an ideal candidate for research into environmental acceptability. In addition to fuel-burn and thrust reductions, the BWB engines are mounted above the fuselage (Figure 8) and the resulting shielding effects considerably reduce fan noise on approach [21].

Noise contours measured on a model at NASA Langley illustrate this reduction (Figure 9). Measurements were made both with and without the wing present. The greatest gain is in

the forward quadrant (18-20 dB), while the rear of the airplane is subject to less reduction due to the presence of jet noise.

Considerable work has already been done in applying optimization tools to maximize the economic benefits of the Blended-Wing-Body, an aircraft that, because of its highly integrated nature, lends itself well to such techniques [22, 23]. Continuing studies using the present design method will indicate the potential for this concept to minimize environmental impact.

5 Conclusion

Application of multidisciplinary optimization to aircraft conceptual design with explicit environmental constraints can identify designs with reduced environmental impact at minimal cost. Employing higher fidelity engine and noise models than are generally used in aircraft synthesis studies and integrating these within an optimization framework, initial application of this design approach was successful in producing optimal solutions. Subsequent work will define the limits to reducing the environmental impact of conventional designs and will explore the potential for unconventional configurations, trajectories, and propulsion concepts to further improve aircraft environmental acceptability.

6 Acknowledgments

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facilitated the validation of the engine simulator.

References

[1] J. D. Erickson, "Environmental Acceptability", Office of Environment and Energy, presented to the Federal Aviation Administration, 2000.

[2] L.J. Archer, *Aircraft Emissions and the Environment*, Oxford Institute for Energy Studies, 1993, p. 1.

[3] The Boeing Company, Boeing Current Market Outlook 2001, http://www.boeing.com/commercial/cmo, 2001.

[4] Emission charges at Swedish airports, http://www.lfv.se/site/lfv/environment/eng/emission_charges.asp, 2000.

[5] *Air & Cosmos*, No. 1789, March 30 2001, p.18-20.

[6] R.H. Liebeck, M.A. Page, B.K. Rawdon, "Blended-Wing-Body Subsonic Commercial Transport," AIAA Paper 98-0438, January 1998.

[7] I. Kroo, V. Manning, "Collaborative Optimization: Status and Directions," AIAA Paper 2000-4721, September 2000.

[8] I. Kroo, "An Interactive System for Aircraft Design and Optimization," AIAA Paper 92-1190, February 1992.

[9] R.A. Zimbrick, and J.L. Colehour, "Investigation of very high bypass ratio engines for subsonic transports," Journal of Propulsion and Power, vol. 6, July-Aug. 1990, p. 490-496.

[10] M.J.T. Smith, *Aircraft Noise*, Cambridge University Press, 1989, p. 248-249.

[11] M.F. Heidmann, "Interim Prediction Method for Fan and Compressor Source Noise", NASA Technical Memorandum X-71763, 1979.

[12] Anon., SAE Aerospace Recommended Practice 876 Rev D: Gas Turbine Exhaust Noise Prediction, Society of Automotive Engineers, Inc., 1994

[13] J.R. Stone, D.E. Groesbeck, and C.L. Zola, "An Improved Prediction Method for Noise Generated by Conventional Profile Coaxial Jets", AIAA Paper 81-1991, 1981.

[14] M.R. Fink, *Airframe Noise Prediction Method*, Federal Aviation Administration FAA-RD-77-29, 1977.

[15] J.E. Penner, *Aviation and the Global Atmosphere*, Cambridge University Press, 1999. p. 76-79.

[16] F. Kennepohl, P. Traub, R. Gumucio, K. Heinig, "Influence of Bypass Ratio on Community Noise of Turbofans and Single Rotation Ducted Propfans," AIAA Paper 95-0135, June 1995.

[17] *Standard Method of Estimating Comparative Direct Operating Costs of Turbine Powered Transport Airplanes*, Air Transportation Association of America, December 1967.

[18] R. Schaufele, *The Elements of Aircraft Preliminary Design*, Aries Publixations, Santa Ana, CA, 2000.

[19] D.P. Rhodes, "Steeper Approaches," Loughborough University, http://www.daz-technology.demon.co.uk/steep2/steep2.html, 1996.

[20] R.E. Caves, L.R. Jenkinson, and D.P. Rhodes, "Development of an Integrated Conceptual Aircraft Design and Noise Model for Civil Transport Aircraft," ICAS Paper 98-6,4,3, 21st ICAS Congress, Melbourne, Australia, Sept. 13-18, 1998.

[21] L.R. Clark and C.H. Gerhold, "Inlet Noise Reduction by Shielding for the Blended Wing Body Airplane," AIAA Paper 99-1937, May 1999.

[22] S. Wakayama and I. Kroo, "The Challenge and Promise of Blended-Wing-Body Optimization," AIAA Paper 98-4736, September 1998.

[23] D. Rodriguez, "A Multidisciplinary Optimization Method for Designing Inlets Using Complex Variables," AIAA Paper 2000-4875, September 2000.

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